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Permion - Specialty Membranes
Radiation Chemistry
Polymer and Electro Chemistry
Water Resources Technology

DEVELOPMENT OF A PROTOTYPE PLASTIC SPACE ERECTABLE SATELLITE

CONTRACT NO. NAS5-3923

with the

National Aeronautics and Space Administration
Goddard Space Flight Center
Greenbelt, Maryland

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1.0 INTRODUCTION

During the current reporting period samples of polyethylene which were sent to the National Metallizing Div. of Standard Packaging Co. to be metallized by aluminum deposition were received. It was found that, although, the samples could be metallized to a required resistance of less than 2 ohms/sq. the dimensional stability of the film could not withstand the metallizing conditions. As a result of this we are at present conferring with NASA to replace aluminum metallization with a more expensive but workable copper metallization. In addition to the work done on metallization the operating variables for the ultrasonic bonder were established during this month. The variables established permit a smooth and strong seal on the irradiated polyethylene film. Work has also been started on the characterization of the memory forces. From the theory of rubber elasticity a mechanical property, namely, modulus of elasticity (E) has been found to be the best indication of the memory forces in a crosslinked plastic above the T_m. Additionally, hysteresis tests were performed on crosslinked polyethylene above its T_m to actually demonstrate the memory on thin film in a "1 G" environment. The results of "E" measurements and the hysteresis tests give conclusive evidence that the plastic memory effect is operative even in a 1 G field.

Finally, the perforation study has been concluded during this reporting period. Data based on flexural rigidity tests of perforated film run during the last month were used to determine the optimum fraction open area which will give the lowest weight without sacrificing required mechanical properties.

It was found that a fraction open area of 0.40 was the optimum value. This void fraction gives a final metallized perforated satellite weight of 847.8 lbs.

2.0 DELIVERABLE ITEMS

2.1 Metallization

In negotiations in scheduling dating back to the spring of 1966 assurances were given to R A I Research Corporation by the National Metallizing Div. of Standard Packaging Co., Trenton, N.J., that polyethylene film could be metallized to approximately 2000 $\mathring{A}$ by the vapor deposition of aluminum. It was found in fact that the film could not be satisfactorily vapor deposited with aluminum. The sequence of steps leading to the delay in metallization is listed as follows:

1. The metallization of copper film for the deliverable items was too costly for the budget of the contract. A quotation of $5,000 was given by Chemical Automation Corporation, Great Neck, N.Y.

2. Aluminum vapor deposition services were then investigated. The National Metallizing Div. of Standard Packaging Co. claimed that they could metallize the required quantities of film with aluminum for a cost of $500.

3. To verify the feasibility of vapor deposition of aluminum on our material samples were sent to National Metallizing on July 8, 1966. They were never returned to us.

4. New samples were sent out on September 6, 1966.

5. They were received metallized on October 10. It was found that the metallization was not satisfactory see Table 1.

6. On October 18, Messrs. V. D'Agostino and P. Keusch of R A I in a meeting with Standard Packaging Co. determined that it would be a considerable risk to attempt to metallize the polyethylene film via aluminum deposition.

The main problem in the deposition of aluminum on polyethylene is the fact that polyethylene has poor heat stability resulting in a loss of dimensional stability during the aluminum deposition application. The loss in dimensional stability becomes greater as the thickness of the aluminum coat applied gets greater (see Table 1). Although it is possible to deposit the required thickness of aluminum to give a satisfactory resistance, the resultant laminate material becomes badly distorted (wrinkled, warped and curled). Even with a deposition thickness of only 500 $\mathring{A}$ the loss in dimensional stability is still observed. The above results indicate that the state of the art of aluminum deposition on polyethylene is not sufficiently advanced to warrant the application of aluminum on polyethylene to obtain a laminate material that has dimensional stability. Due to the inability of outside metallizing firms to adequately metallize the polyethylene to required specifications within the budget of the contract, R A I will metallize the necessary quantities of film for the deliverable items. The metallization will be done using the electroless deposition of copper using Enthone's electroless plating cycle. An operating procedure similar to the one used to plate mesh will be used to plate the film.[1] A copper thickness of 7×10^{-6} inches will be applied on both sides of the film.

2.2 Ultrasonic Bonding

The conditions for the ultrasonic bonding of irradiated PE 12 were established. The operating variables determined are

Table 1

Properties of Aluminized Polyethylene Film, Aluminized by National Metallizing Div. of Standard Packaging Co., Trenton, N.J.

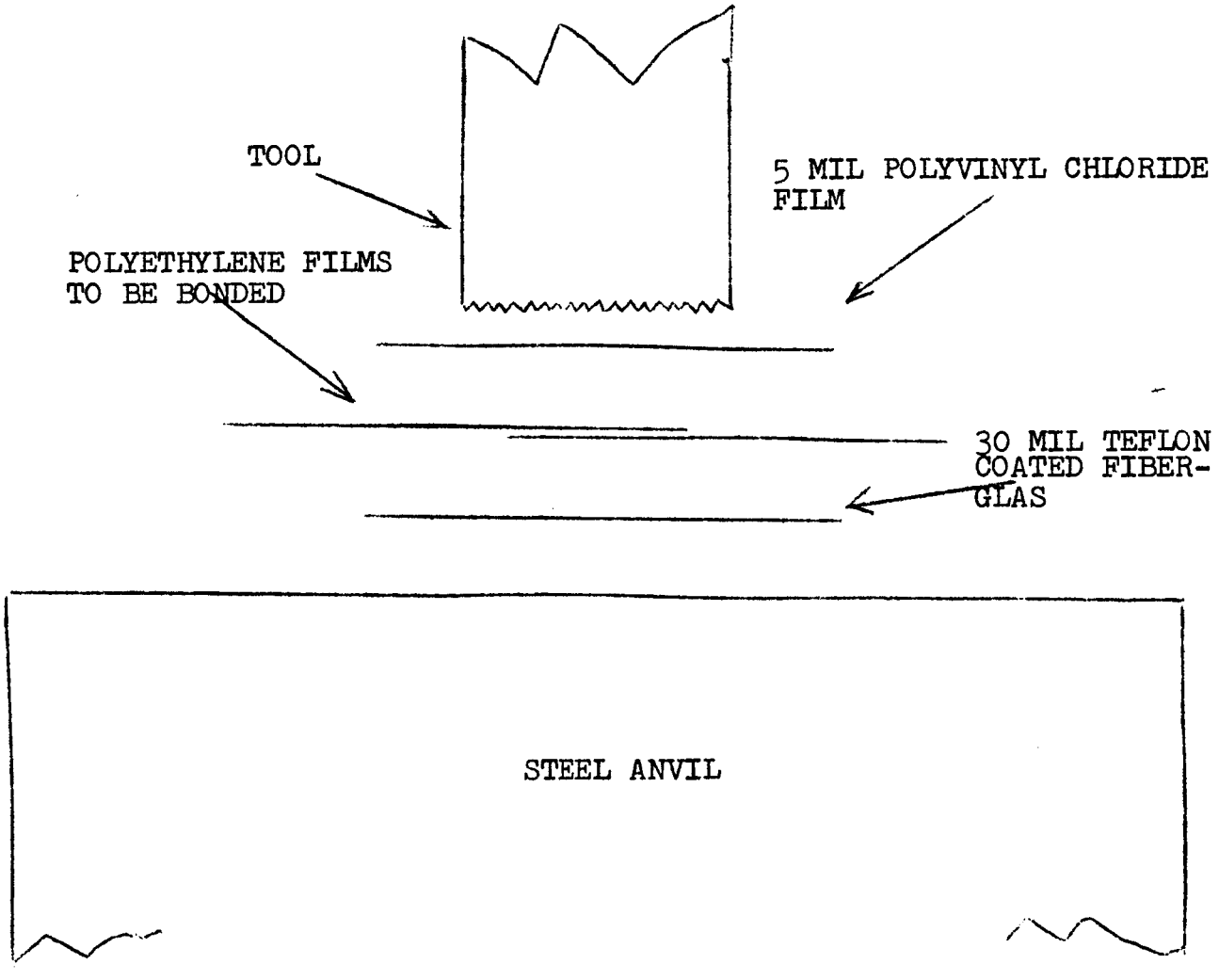
Film Type	Aluminum Thickness (angstrom)	Sample Size (in. x in.)	Resistance (ohms/sq.)	Description
Run # I PE 12				
Unirradiated	1500	2 x 3.5	0.85	badly wrinkled
Irradiated	1500	2 x 3	0.30	badly wrinkled and black
Irradiated, Heat Treated	1500	2 x 3.5	0.57	badly wrinkled
Unirradiated	2800	2 x 3.5	1.14	wrinkled, black
Irradiated	2800	1.5 x 3	0.75	wrinkled
Irradiated, Heat Treated	2800	2 x 3.5	0.85	wrinkled, slightly black
Run # II				
Unirradiated (PE 12)	500	3 x 5	2.00	wrinkled
Irradiated (PE 11)	500	11.5 x 11.5	4.50	wrinkled
Irradiated (PE 11)	500	11 x 9	5.00	wrinkled

are listed as follows:

Frequency: 20,000 Kc
Power: 400 Watts (full scale, tuned)
Depth of Penetration: 5 mils
Pressure: 35 lbs.
Contact time: 2.5 seconds (generator on 1.5 seconds)
Tool: 1/4 inch x 2½ inches (inverse knurled Monel metal)

Additionally, 30 mil Teflon coated fiberglas was needed below the sample while 5 mil polyvinyl chloride film was needed above the sample for adequate bonding (see Figure 1 below).

Figure 1. ULTRASONIC BONDING SCHEMATIC



3.0 CHARACTERIZATION OF MEMORY FORCES

It has been found by an investigation of the literature concerning the theory of rubber elasticity that memory forces (of a crosslinked material) can be characterized above the T_m by measurement of the modulus of elasticity (E) of the film. It has been determined theoretically that the modulus of elasticity can be given by the following equations:

$$E = 3 \nu KT \quad \text{(refs. 2,3)}$$

where T = absolute temperature (above T_m)
K = Boltzmann constant

$$\nu = \frac{N \rho}{M_c} \left(1 - \frac{M_c}{M_n}\right)$$

where N = Avagadro's Number
ρ = density
M_c = molecular weight between crosslinks
M_n = number average molecular weight

With the above equations as a guide it is now possible for the first time to conclusively prove that very thin, crosslinked polyethylene film exhibits a plastic memory. In unirradiated thermoplastics, i.e., linear polymers, once the T_m is exceeded the plastic exhibits permanent flow properties and the memory phenomenon is not observed. Irradiation of the thermoplastic, however, causes the development of crosslinks in the thermoplastic, thereby, changing the linear structure to the three-dimensional network. Radiation, in effect, vulcanizes the plastic and makes it an elastomer. The elastomeric properties, however, are not observed at temperatures below the T_m because the crystalline force is much greater than the memory force. When the crystalline force is eliminated by exceeding the melting point the memory force is observed. In this way, the memory forces of the crosslinked polyethylene film can be characterized

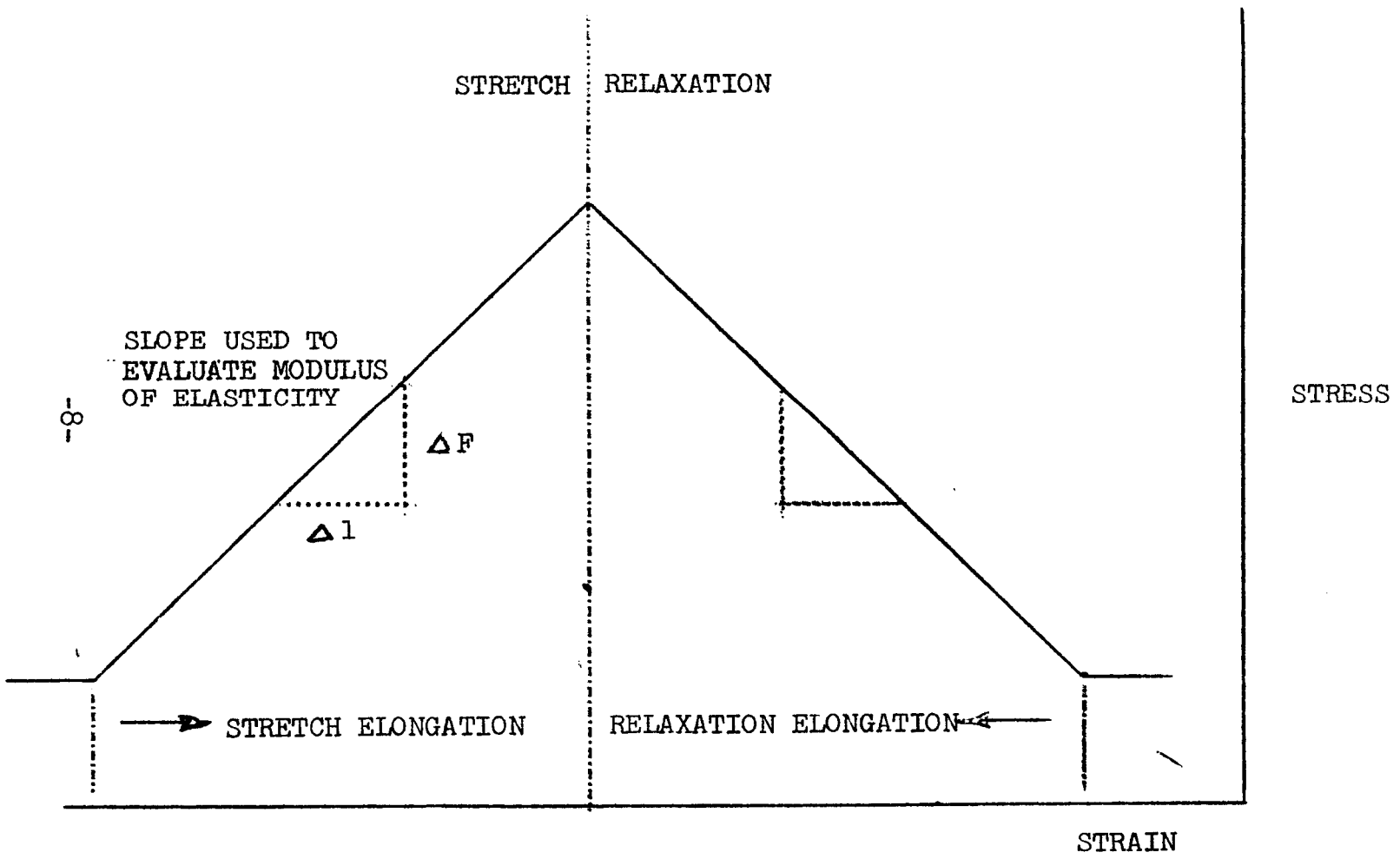
by measuring E above T_m. A tensile test performed above the T_m is conducted and the modulus of elasticity is measured. This modulus is then a direct indication of the memory force exhibited in the crosslinked polyethylene film. Additionally, after the film is deformed, the tension is released and the film springs back to its original dimensions thereby completing a memory cycle. If the film were not crosslinked the modulus of elasticity above the T_m would be essentially zero, and the film would exhibit permanent set characteristics after any deformation. These experimental results based on the above theory have been demonstrated (see Table 2 and Figure 2 below). It can be seen from these results that the crosslinked film does possess a modulus of elasticity above the T_m and that additionally, the film can be deformed and restored (cycled with minimal hysteresis loss) to its original dimensions when it is above its T_m. Furthermore, the results qualitatively conform to the above equation. As irradiation dose is increased the molecular weight between crosslinks decreases thereby resulting in a stronger film.

Table 2

Characterization of Memory Forces - Modulus of Elasticity, E, PE 12 Irradiated to 15 and 70 Mrads, Strain Rate 2 in./min.

	120°C.		140°C.	
Dose Mrads	E (psi x 10^3)	Cycle	E (psi x 10^3)	Cycle
15	0.044	Complete	0.033	Complete
70	0.343	-	0.338	-

Figure 2. TYPICAL STRESS CURVE OF ELASTOMERIC POLYETHYLENE



4.0 BUCKLING PRESSURE THICKNESS CALCULATIONS

4.1 Perforation Optimization with Respect to Satellite Weight

With the critical buckling pressure equations given as:

$$P_{cr} = \frac{\hat{G}^F(t)}{t} \frac{24}{\pi R^2 k^{\frac{1}{2}}} \left(10^{-2} \frac{k\rho}{4} + \frac{1}{\rho}\right) \qquad (1)$$

Modification for the effects of perforation can be applied as follows:

$$(1 - F_v)P_{cr} = \frac{\hat{G}_P^F(t)}{\hat{G}^F(t)} \frac{\hat{G}^F(t)}{t} \frac{24}{\pi R^2 k^{\frac{1}{2}}} \left(10^{-2} \frac{k\rho}{4} + \frac{1}{\rho}\right)$$

or
$$\frac{1 - F_v}{Q(F_v)} \cdot H(t) = F^c(\rho) \qquad (2)$$

where $F^c(\rho) = \frac{24}{\pi R^2 k^{\frac{1}{2}}} \left(\frac{10^{-2} k\rho}{4} + \frac{1}{\rho}\right)$

F_v = void fraction

$$H(t) = \frac{t}{\hat{G}^F(t)}$$

$$Q(F_v) = \frac{\hat{G}_P^F(t = 0.27)}{\hat{G}^F(t = 0.27)} = \frac{\text{Flexural Rigidity after Perforation}}{\text{Flexural Rigidity before Perforation}}$$

(with other variables defined in quarterly reports RAI 368 March-May 1966, pp. 14-17, and RAI 370 June-August, 1966, pp. 14-15).

Equation (2) may be further modified in the following way:

$$H(t) = \frac{F^c(\rho)}{A(F_v)} \qquad (3)$$

where $A(F_v) = \frac{1 - F_v}{Q(F_v)}$

The safest film thickness of an unperforated laminate must satisfy the relation $H(t) = \min F^c(\rho)$. For a given void fraction F_v the safest thickness of film required to withstand the specified buckling pressure must satisfy the following equation

$$H(t) \leq \frac{\min F^c(\rho)}{A(F_v)} \tag{4}$$

or, conversely, for a given thickness a safe void fraction must satisfy equation (4). With $H(t)^*$ established from $\min F^c(\rho)$, Figure 3, for unperforated laminate and the safe F_v requirement established by equation (4), it follows that $A(F_v) \leq 1$. With this condition established, the optimum void fraction, F_v, that allows $W_A = (1 - F_v)(\rho t + \rho_{cu}(t_{cu})$ to be a minimum can be determined. From the $A(F_v)$ curve (Figure 5) experimentally established[4] (from flexural rigidity ratios $Q(F_v)$ see Fig. 4) and the condition $A(F_v) \leq 1$, F_v is found to be 0.40. Due to the fact that data could be only actually taken up to $F_v = 0.40$ and the fact that $A(F_v) = \frac{1 - F_v}{Q(F_v)}$ can increase, above 0.40, since $Q(F_v)$ will decrease due to losses in rigidity from large fractions of open area, $F_v = 0.40$ was chosen to be the safe optimum point.

From the value of $F_v = 0.40$ and the unperforated satellite weight found to be 1,413 lbs. (quarterly report RAI 370, June-Aug. 1966, p 19), the final perforated satellite weight is found to be:

$$W_T = (1 - F_v)(1413) = 0.60(1413) = 847.8 \text{ lbs.}$$

*Film thickness of 0.27 mil electrolessly plated with copper to 15×10^{-6} inches on both sides

Figure 3: THE FUNCTION $F^c(\rho) = \frac{24}{\pi R^2 k^{\frac{1}{2}} P_{cr}} \left(\frac{10^{-2k}\rho + 1}{4} \right)$

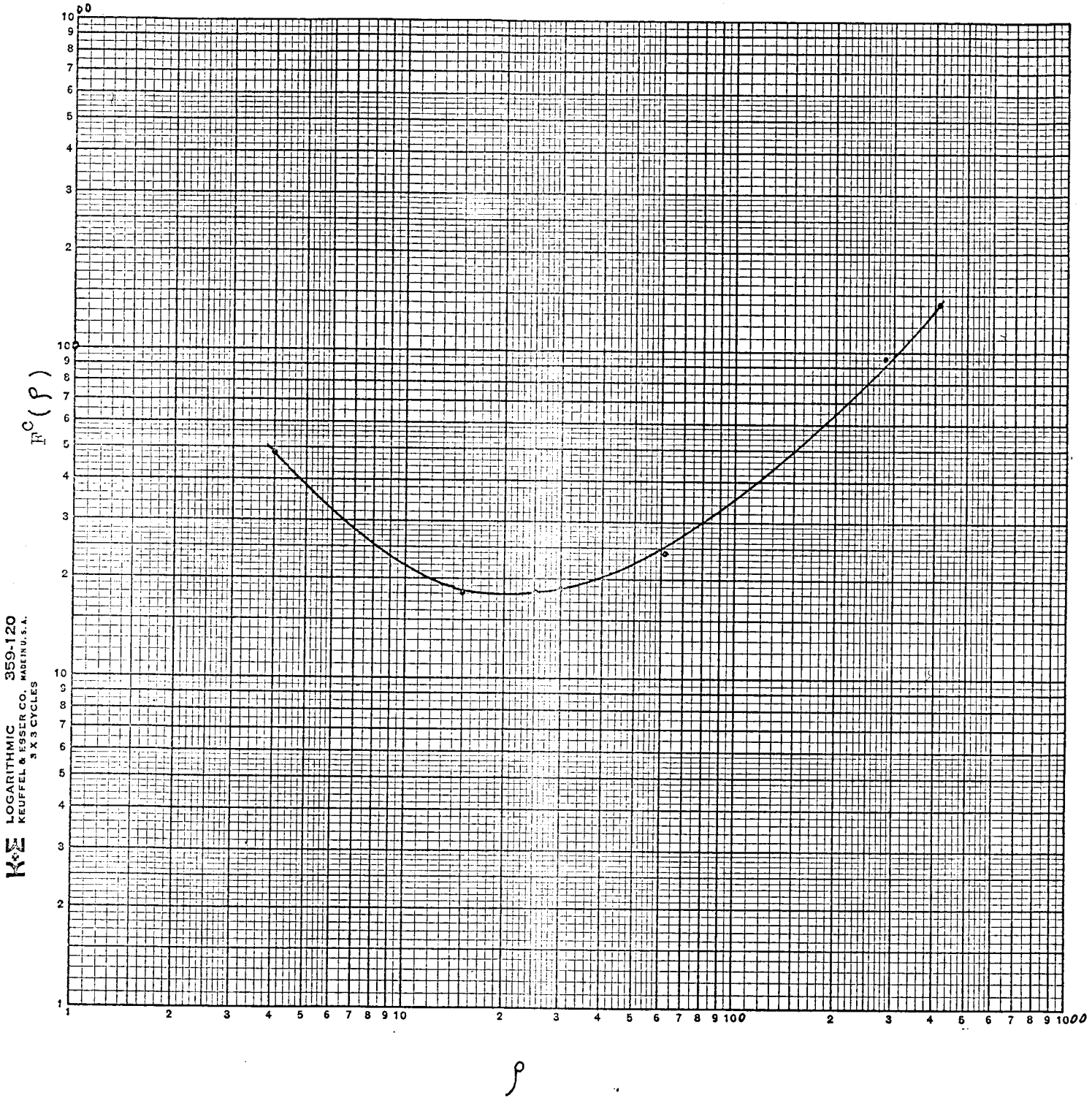


Figure 4. RATIO OF FLEXURAL RIGIDITIES $Q(F_V)$ AFTER PERFORATION TO BEFORE PERFORATION FOR 0.27 MIL POLYETHYLENE COATED WITH 15×10^{-6} INCHES OF COPPER ON BOTH SIDES

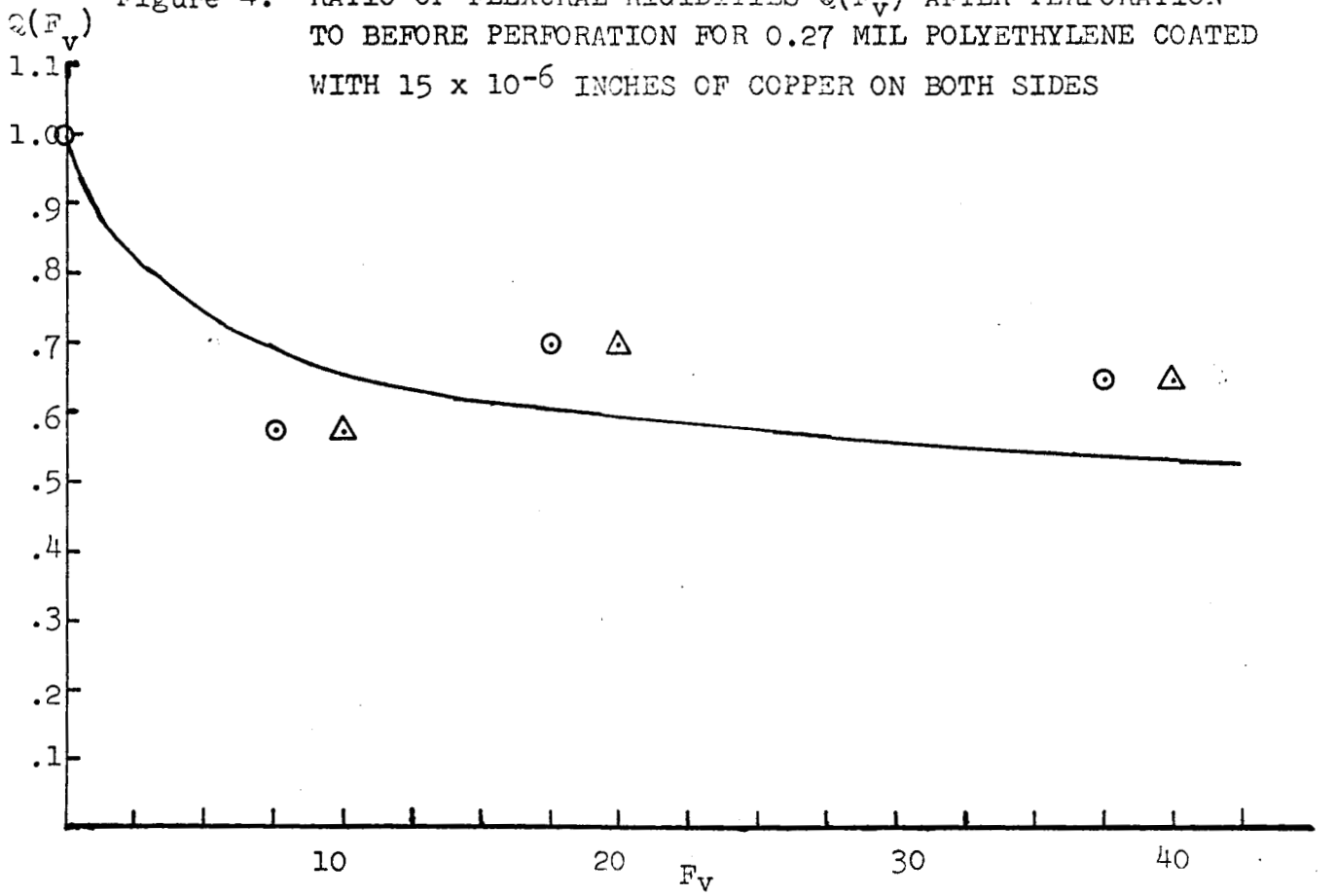
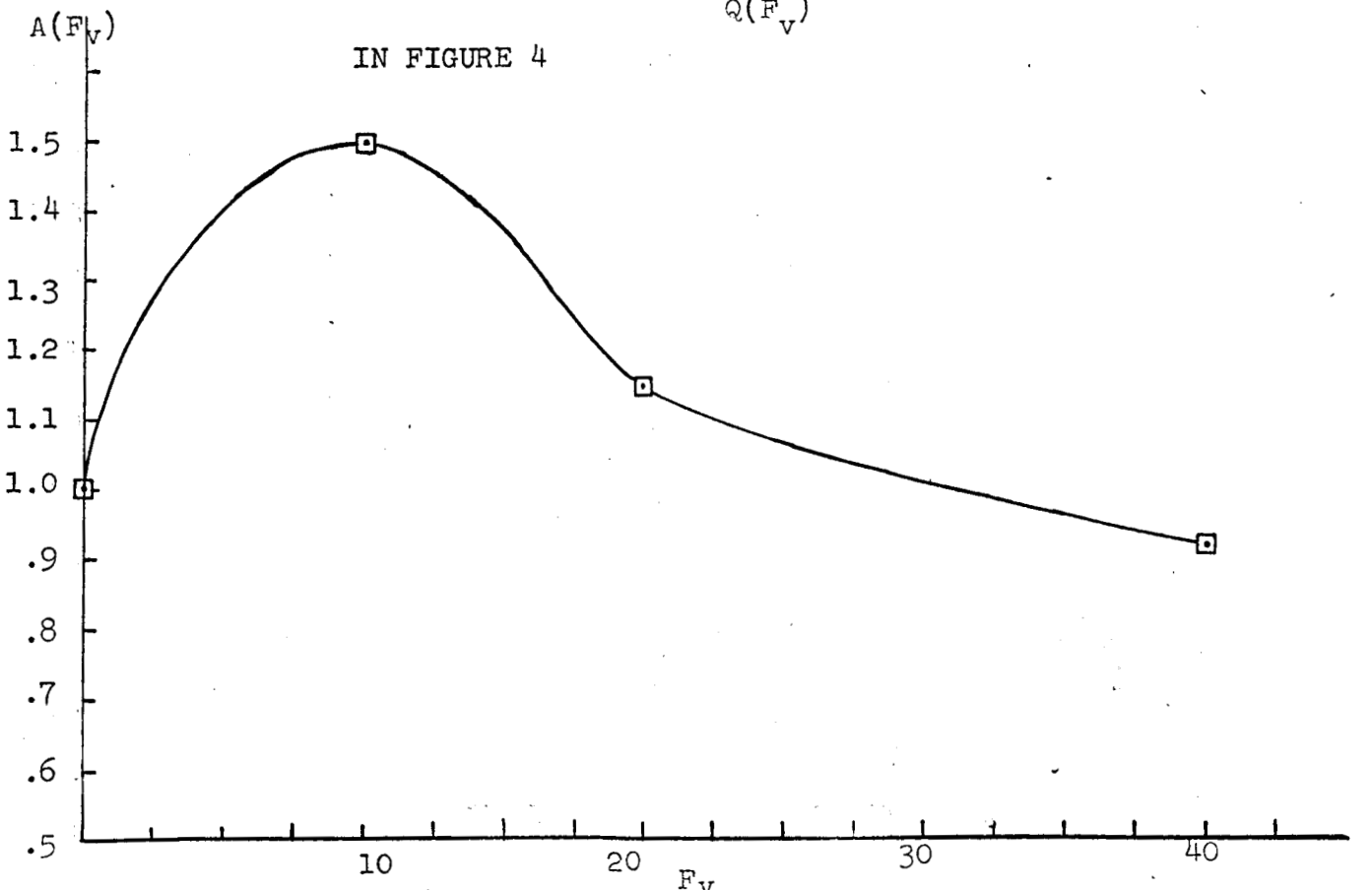


Figure 5. THE FUNCTION $A(F_V) = \frac{1 - F_V}{Q(F_V)}$ WHERE $Q(F_V)$ IS GIVEN IN FIGURE 4



5.0 FUTURE WORK

During the next reporting period, work will be continued on the fabrication of the deliverable items. In addition, the testing program will be completed using the final film metallized with copper by the Enthone electroless plating cycle and perforated to ca. 25% open area.

6.0 REFERENCES

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3. Flory, P., "Principles of Polymer Chemistry," Chapter XI, pp. 432-493, Cornell University Press, Ithaca, N.Y., 1953.

4. RAI Monthly Report, Sept. 1966, pp. 2-5.